Estimating Farm-Level Effects of Adopting Herbicide-Tolerant Soybeans

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Abstract: The farm-level effects of adopting herbicide-tolerant soybeans obtained from various data sources are compared and evaluated. In 1997, adopters' yields were estimated to be only 3 percent higher than for nonadopters. In the Heartland region, where about two-thirds of U.S. soybeans are grown, adopters' weed control costs were estimated to be 11 percent lower than for nonadopters, a savings of $3.50 per acre. Weed control cost savings were estimated to range from 1 percent to 34 percent in other regions. While the impact on herbicide use (measured in pounds of active ingredients) is mixed among production regions—a decline for the Heartland and Prairie Gateway but an increase for all other regions—overall there is a slight increase. Still, adoption of herbicide-tolerant soybeans may lead to positive environmental and health benefits. According to the elasticity-based estimates, the benefits to U.S. farmers in 1997 were estimated to have been about $60 million, or about 20 percent of the total benefits to all stakeholders from the adoption of the technology.

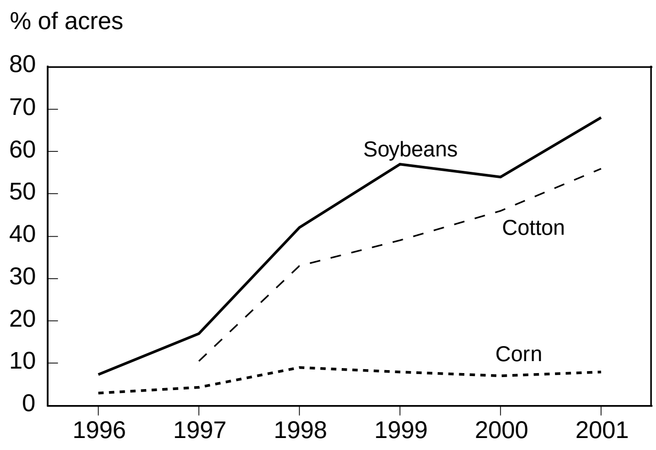
Keywords: Herbicide-tolerant soybeans, farm-level effects, crop yields, weed control costs, herbicide use.

Introduction

The adoption of herbicide-tolerant soybeans has been particularly rapid in the United States, increasing from less than 10 percent of soybean acreage in 1996, when the technology was introduced, to nearly 70 percent in 2001 (USDA, 2001; fig. B-1). The rapid adoption has reflected the benefits of potential increases in crop yields and savings in pest control costs from this technology. But more importantly, herbicide-tolerant soybeans offer producers the simplicity and flexibility of a weed control program that relies on one herbicide to control a broad spectrum of weeds without crop injury or crop rotation restrictions (Carpenter and Gianessi, 1999_b). Thus, estimates of the benefits from adopting herbicide-tolerant soybeans and their distribution among the stakeholders require accurate information about the technology's farm-level impacts on crop yields, pest control costs, and the ease of weed control management.

Estimates of the farm-level effects differ significantly, depending on the data source. For example, a recent study of the distribution of benefits from biotech adoption by Falck-Zepeda, Traxler, and Nelson assumed that adopters' yields for 1997 herbicide-tolerant soybeans were 13.0 percent higher than nonadopters in the Corn Belt based on data from the U.S. Department of Agriculture's Agricultural Resource Management Study (ARMS) survey. In contrast, Moschini *et al.* studied the welfare effects of herbicide-tolerant soybean adoption by assuming no yield difference,

Figure B-1
Adoption of herbicide-tolerant soybeans has been quite rapid. . .



Source: USDA's ARMS survey for 1996 and 1997; USDA's June 2001 *Acreage* report and March 2000 *Prospective Plantings* reports for 1998 and 1999; Adoption in 1998-99 includes both biotech and conventional varieties. Adoption includes both herbicide-tolerant only and stacked gene varieties for corn and cotton.

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adapted from a costs-of-production budget for Iowa (Duffy and Vontalge). Differentials in mean crop yields between adopters and nonadopters from the ARMS survey reflect the combined effect of biotechnology and other confounding factors, such as production practices. The effects on pest control costs differ even more dramatically across data sources than the impacts on crop yields.

Variations among differing estimates warrant further evaluation of these farm-level effects and a concerted effort to find ways to reconcile the differences. Accordingly, the purpose of this article is to compare and evaluate the farm-level effects of adopting herbicide-tolerant soybeans obtained from various data sources. The analysis focuses on 1997 herbicide-tolerant soybeans in the United States for which the latest detailed ARMS survey data are available. The key data sources that we compared and evaluated include: (1) the means of the ARMS survey, and (2) the elasticity-based estimates obtained by isolating the effect of biotechnology through econometric analysis of the ARMS survey data (Fernandez-Cornejo *et al.*). Yield and herbicide use elasticities from their adoption-impact model are further analyzed in this study to show yield and per-acre weed control cost differentials between adopters and nonadopters. In addition, costs-of-production budgets or agronomic research from selected States, where applicable data are available, are compared with the ARMS data analysis and elasticity-based estimates. Results are used to compare alternative estimates of producer benefits from the adoption of herbicide-tolerant soybeans and implications for herbicide use.

Data Sources

The estimates of potential increases in crop yields and savings in weed control costs induced by the adoption of herbicide-tolerant soybeans are among the most difficult variables in measuring the benefits from adopting this technology. This section discusses two data sources that were used to estimate the farm-level effects of adopting herbicide-tolerant soybeans.

The ARMS survey, a Nationwide producer survey conducted by USDA to monitor economic and environmental indicators in the U.S. farm sector, is a data source used by some researchers to estimate the farm-level impacts (Falck-Zepeda, Traxler, and Nelson). Farm financial and chemical use data are reported for all crops in the ARMS survey each year, while detailed enterprise production practices and cost data are collected for several commodities (including soybeans) on a rotating basis every 4 to 7 years (McBride).[2]

[2] The 1997 ARMS data are used in this study because these are the latest available for soybeans. The 1997 data are based on a relatively small number of adopters. Only about 12 million acres (17 percent) of herbicide-tolerant soybeans were planted that year. Availability of herbicide-tolerant soybean seed varieties suited for northern States (Minnesota, Wisconsin) was quite limited in 1997.

There are four characteristics of the ARMS data that make it particularly useful for assessing the farm-level impacts of biotechnology adoption (McBride). First, the ARMS survey has a broad coverage, including all major States producing a particular commodity, and generally covers more than 90 percent of the acreage of targeted commodities. Second, the ARMS survey uses a stratified random sample where each farm represents a known number of similar farms in the population based on its probability of being selected. Each farm is weighted by the number of farms it represents so that the ARMS sample can be expanded to reflect the targeted population. Third, ARMS enterprise costs-of-production data contain sufficient detail about specific inputs to isolate the seed and pest control costs used to produce a given commodity. Finally, enterprise costs of production can be estimated for each observation in the ARMS data so that a distribution of costs can be developed. However, data from farm surveys like the ARMS are more expensive to obtain and are more difficult to use than State cost budgets. More importantly, the data do not easily lend themselves to estimating the farm-level impacts solely attributed to the adoption of biotechnology. Mean crop yield and pest control cost differentials between adopters and nonadopters often reflect not only the effect of biotechnology adoption but also other factors, such as production practices, soil productivity, farm size, and the managerial ability of farm operators.

An alternative to estimating mean differentials from the survey data is to estimate the impacts of biotechnology adoption by statistically isolating the effects of the technology through econometric analysis (Fernandez-Cornejo, Klotz-Ingram, Jans; Fernandez-Cornejo and McBride). The econometric model is also estimated from ARMS survey data but takes into account the fact that farmers' adoption of biotechnology and pesticide-use decisions may be simultaneous. In addition, the model corrects for self-selectivity to prevent biasing the results. Self-selection arises because farmers are not randomly assigned to one of two groups—adopters and nonadopters; instead, they make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different from each other, and these differences may manifest themselves in farm performance, which could confound the effect of adoption.

The results of this two-stage impact model are expressed in elasticity form. In terms of the impact on crop yields (an elasticity of +0.03), the adoption of herbicide-tolerant soybeans has a positive and statistically significant effect, but it is small—U.S. herbicide-tolerant soybean yields in 1997 are estimated to have increased by 0.3 percent for a 10-percent increase in adoption across the Nation. This yield effect is generally consistent with other studies (Gianessi and Carpenter; Carpenter and Gianessi, 2000; Carpenter and Gianessi, 1999_b; Moschini, Lapan, and Sobolevsky; Duffy and Vontalge).

The impact of adopting glyphosate-tolerant soybeans on herbicide use, based on this econometric model, varies across active ingredients. Glyphosate is the active ingredient in Roundup, the broad-spectrum herbicide that Monsanto developed its Roundup-Ready soybeans to resist. Formerly, only pre-emergence applications of glyphosate on soybeans were possible without crop injury. An increase in the adoption of glyphosate-tolerant soybeans is estimated to have led to statistically significant reductions in the use of herbicides other than acetamides (such as metolachlor and alachlor) and glyphosate (an elasticity of -0.14) and a significant increase in the use of glyphosate (an elasticity of +0.43). Thus, use of other synthetic herbicides is estimated to have decreased by 1.4 percent for a 10-percent increase in adoption of herbicide-tolerant soybeans. In contrast, use of glyphosate is estimated to have increased by 4.3 percent. The change in acetamides use was not statistically significant.

Estimated Impacts on Crop Yields

A fundamental question that needs to be addressed before estimating the benefits from adopting herbicide-tolerant soybeans is: "How much of the difference in crop yields between adopters and nonadopters is attributable to the adoption of the technology?" This section discusses the impacts of adopting herbicide-tolerant soybeans on crop yields mainly across two data sources: (1) the mean values for adopters and nonadopters obtained from the ARMS survey, and (2) the analysis based on the elasticities derived from the adoption-impact model. Other data sources, such as State variety trials or agronomic research, are also discussed.

The impact of adopting herbicide-tolerant soybeans on crop yields, based on one year of data (1997), appears to vary significantly across data sources and production regions (fig. B-2). There are significant differences in the impacts of adopting herbicide-tolerant soybeans between estimates from the mean ARMS data and the elasticity-based estimates. In the Heartland region, while adopters' 1997 yields are shown to have been 14.2 percent higher than those of nonadopters (averaging 44.4 bushels per acre), based on the mean ARMS data, the elasticity-based estimate indicates only a 3-percent higher yield for adopters (fig. B-3). Heartland producers account for 64 percent of U.S. soybean acreage and 56 percent of the herbicide-tolerant soybean area. The small, 3-percent increase in yields based on the elasticity estimate statistically removes factors other than biotechnology, such as production practices, farm operator's managerial ability, soil productivity, and weather, which affect crop yields. Thus, the elasticity-based estimate reflects the impact on crop yields that is attributable to the technology, and is consistent with findings of other studies. That is, the adoption of herbicide-tolerant soybeans has little or no overall impact on U.S. soybean yields (Gianessi and Carpenter; Duffy and Vontalge; Moschini, Lapan, and Sobolevsky). Similar patterns also exist for the Southern Seaboard, Prairie Gateway, and Northern Great Plains regions (table B-1). Thus, studies using mean yields from the ARMS survey (e.g., Falck-Zepeda, Traxler, and Nelson) would overestimate the benefits from biotech adoption for U.S. soybean farmers.

Despite conflicting evidence, yield trials and costs-of-production budgets from selected States suggest that, overall, there is little difference in yields between herbicide-tolerant soybeans and conventional varieties. In 1998, yields of herbicide-tolerant soybeans were reported to have been 4 percent lower than conventional varieties (about 1 bu./ac.) based on variety trials from more than 3,000 side-by-side comparisons across 40 university performance tests in eight States (Oplinger). However, comparisons in yield trials are made under weed-free conditions and do not necessarily represent farm conditions where imperfect weed control leads to some yield losses, particularly for the case of conventional varieties. Many analysts believe these yield drags will disappear as more backcrosses are made to capture the yield potential in the parent lines. In addition, agronomic research in Minnesota concluded that there was no difference in yields between herbicide-tolerant soybeans and conventional varieties (Breitenbach and Hoverstad).

Estimated Impacts on Weed Control Costs

Another fundamental question that needs to be addressed before estimating the benefits from adopting herbicide-tolerant soybeans is: "How much of the difference in weed control costs between adopters and nonadopters is attributable to the adoption of the technology?" This section discusses the impacts of glyphosate-tolerant soybeans on weed control costs (including expenses associated with herbicides, herbicide application, scouting, and cultivation) across the data sources.

Weed control costs for glyphosate-tolerant soybean adopters were lower in 1997 than those incurred by nonadopters (table B-2).[3] However, adopters' savings in weed control costs based on means of the ARMS survey were generally much higher than those based on the elasticity-based estimates. For example, while soybean weed control costs in the Heartland were 31 percent lower for adopters than an average of $33.05 per acre for nonadopters based on the mean ARMS data, the saving is estimated with the elasticity-based approach to be 11 percent. Similar patterns exist between the two data sources for other regions.

The elasticity-based estimates of the difference in weed control costs between adopters and nonadopters are based on

[3] This result is consistent with the finding by Marra *et al.* that in 1996, total herbicide costs decreased despite an increase in glyphosate use—glyphosate costs rose by $13/ac. while expenditures for other herbicides fell by $24/ac. In 1999, 0.98 pound per acre of herbicides were applied on soybeans, down from 1.01 pounds per acre in 1995 (Carpenter and Gianessi, 2000).

Figure B-2

ERS crop production regions

Basin and Range

- Largest share of nonfamily farms, smallest share of U.S. cropland.
- 4% of farms, 4% of value of production, 4% of cropland.
- Cattle, wheat, and sorghum farms.

Northern Great Plains

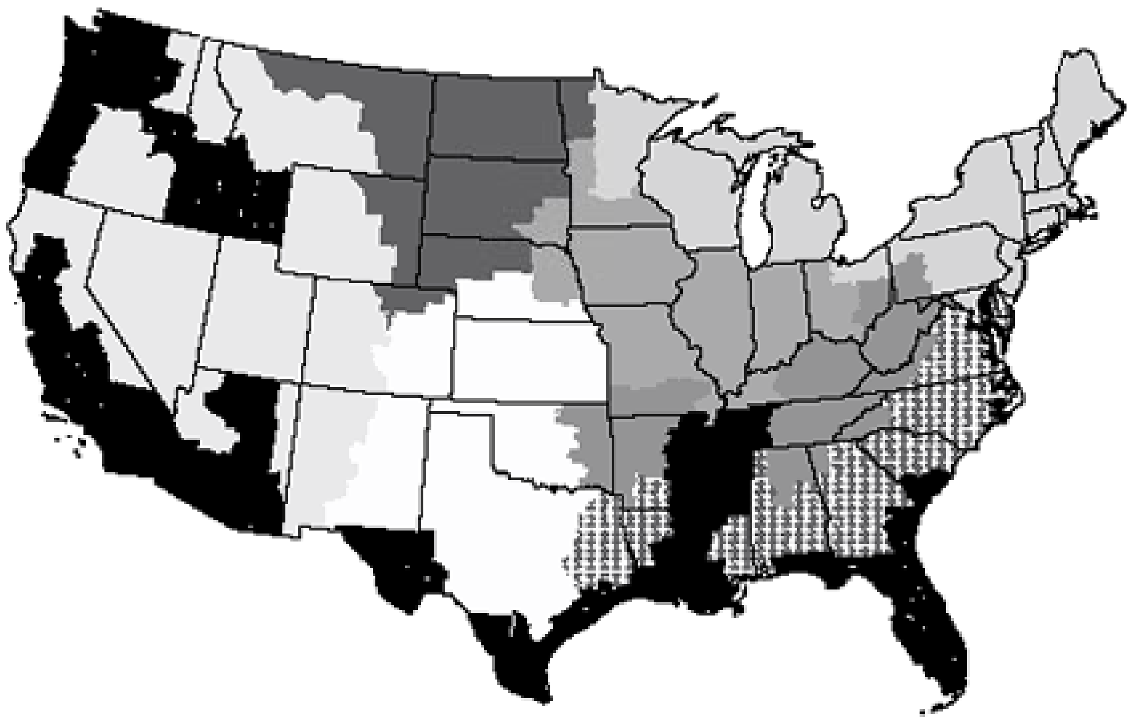
- Largest farms and smallest population.
- 5% of farms, 6% of value of production, 17% of cropland.
- Wheat, cattle, and sheep farms.

Heartland

- Most farms (22%), highest value of production, (23%), and most cropland (27%).
- Cash grain and cattle farms.

Northern Crescent

- Most populous region.
- 15% of farms, 15% of value of production, 9% of cropland.
- Dairy, general crop, and cash grain farms.



Fruitful Rim

- Largest share of large and very large family farms and nonfamily farms.
- 10% of farms, 22% of value of production, 8% of cropland.
- Fruit, vegetable, nursery, and cotton farms.

Prairie Gateway

- Second in wheat, oat, barley, rice, and cotton production.
- 13% of farms, 12% of value of production, 17% of cropland.
- Cattle, wheat, sorghum, cotton, and rice farms.

Mississippi Portal

- Higher proportions of both small and lager farms than elsewhere.
- 5% of farms, 4% of value of production, 5% of cropland.
- Cotton, rice, poultry, and hog farms.

Southern Seaboard

- Mix of small and larger farms.
- 11% of farms, 9% of value of production, 6% of cropland.
- Part-time cattle, general field crop, and poultry farms.

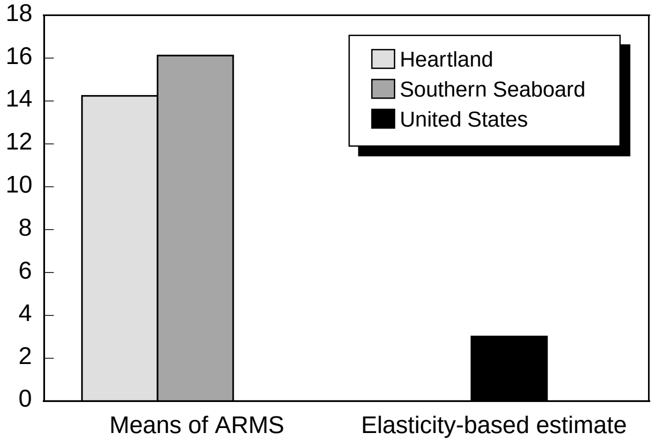
Eastern Uplands

- Most small farms of any region.
- 15% of farms, 5% of value of production, and 6% of cropland.
- Part-time cattle, tobacco, and poultry farms.

Figure B-3

Impact on crop yields: Herbicide-tolerant soybeans, 1997

% of adopters' yield increases



Source: USDA's ARMS Survey; Fernandez-Cornejo, Klotz-Ingram, and Jans.

the elasticities determined by Fernandez-Cornejo, Klotz-Ingram, and Jans (see box). Herbicide material costs for adopters are estimated by acounting for any potential savings in herbicide use, ingredient-by-ingredient, assuming application rates of each active ingredient are the same for adopters and nonadopters. Savings in herbicide material costs are based on herbicide use elasticities estimated by Fernandez-Cornejo, Klot-Ingram, and Jans— +0.43 for glyphosate and -0.14 for 'other synthetic herbicides.' The -0.14 elasticity for other synthetic herbicides means that adopters' herbicide use would have been about 14 percent lower than nonadopters' herbicide use. Thus, expenses in 1997 associated with the other herbicides were $24.30 per acre for nonadopters compared with $20.90 per acre for

Table B-2--Impact of adopting herbicide-tolerant soybeans on per-acre weed control costs, 1997

Production region	Difference in weed control costs between adopters and nonadopters: Means of ARMS	Elasticity-based estimate
	Percent	
Heartland	-30.89**	-10.68
Northern Crescent	+8.77	-12.21
Southern Seaboard	-44.78**	-3.91
Northern Great Plains	+8.88**	n.a.
Mississippi Portal	-27.18**	-4.45
Prairie Gateway	-0.89	-0.89
Eastern Uplands	-33.92	-33.92

n.a.= Not available.
**Per-acre herbicide costs of herbicide-tolerant seed are statistically different from other purchased seed at the 5-percent level.
Sources: McBride and Brooks; Fernandez-Cornejo, Klotz-Ingram, and Jans.

adopters. No significant change occurred in the use of acetamides. In contrast, per-acre glyphosate material costs were about $1.16 per acre higher for adopters in the Heartland, increasing from $2.70 for nonadopters to $3.86 for adopters. However, the decline in expenses associated with the use of other herbicides—$3.40 per acre—more than offset the increase in expenses for glyphosate. As a result, adopters' expenses for all herbicide materials totaled $25.64 per acre, lower than the $27.89 per acre for nonadopters.[4] Adopters of herbicide-tolerant soybeans in the Heartland region are estimated to have realized a 10.68-percent weed

[4] With the expiration of Monsanto's patent on glyphostae in 2000, the cost of the chemical has dropped as generic products are now available. This will likely expand the current cost savings from the 1997 estimates. The competition from Roundup probably forced other herbicide producers to cut their prices to maintain market share. Glyphosate price declined from $56.70/gallon in 1997 to $43.30/gallon in 2000.

Table B-1--Impact of adopting herbicide-tolerant soybeans on crop yields by region and by data source, 1997

Production region	Soybean planted acreage		Herbicide-tolerant soybeans: Acreage	Adoption rate	Adopters' yield differences from nonadopters: Means of ARMS	Elasticity-based estimate
	1,000 ac.	Percent	1,000 ac.	Percent	Percent	
Heartland	44,936	64.2	6,606	14.7	+14.23**	n.a.
Northern Crescent	5,628	8.0	856	7.0	-0.01	n.a.
Southern Seaboard	3,430	4.9	593	17.3	+16.13*	n.a.
Mississippi Portal	8,064	11.5	2,484	30.8	-0.09	n.a.
Prairie Gateway	3,794	5.4	664	17.5	+20.00**	n.a.
Eastern Uplands	1,190	1.7	417	35.0	+5.00	n.a.
Northern Great Plains	2,562	3.7	179	7.0	+10.81	n.a.
Fruitful Rim	399	0.6	0	0	n.a.	n.a.
U.S. total	70,005	100.0	11,798	17.0	n.a.	+3.0

n.a. = Not available.
**Significantly different from all other at the 5-percent level.
* Significantly different from all other at the 10-percent level.
Sources: McBride and Brooks; Fernandez-Cornejo, Klotz-Ingram, and Jans.

Procedures to calculate the difference in per-acre weed control costs between adopters and nonadopters of herbicide-tolerant soybeans

The first step to calculate the impact of adopting herbicide-tolerant soybeans on weed control costs is to estimate expenses associated with herbicide material for nonadopters in a specific production region, such as the Heartland. Based on NASS' chemical use data, the herbicide application rate per crop year and the percent of area applied with herbicide are tabulated by herbicide ingredient at the regional level, based on State data (table B-3). Herbicide-active ingredients are grouped into three categories: acetamides, glyphosate, and other synthetic herbicides. Price data for herbicide-active ingredients are obtained from NASS (1998) and from a database of 1996 prices developed by Gianessi and Marcelli. In cases where herbicide prices were expressed in terms of dollars per pound of active ingredient, no adjustment of the price data was necessary. However, in cases where price data were shown for final products in dollars per gallon, the final product price was divided by the product-active ingredient conversion ratio (lb/gal) to obtain prices for active ingredients ($/lb).

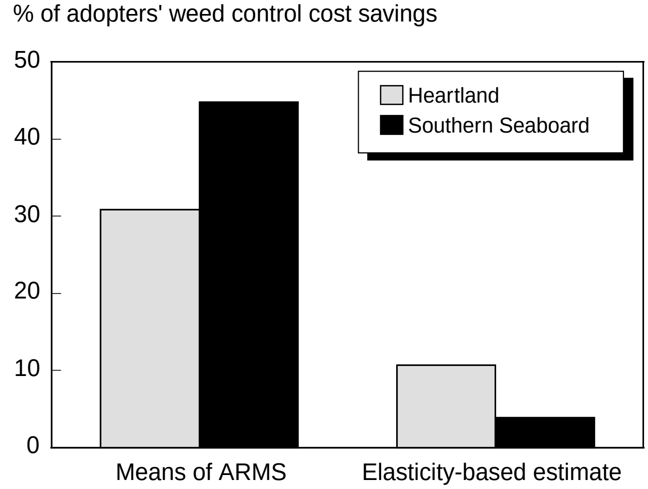
Multiplying the active ingredient price by a weighting factor, which is the product of the application rate per crop year and the percent of area applied, gives the expense associated with a specific active ingredient for nonadopters. Continuing this calculation for all active ingredients and adding up the expenses across active ingredients result in the total per-acre expense associated with herbicide materials—$27.89 for nonadopters of herbicide-tolerant soybeans in the Heartland. Including expenses for herbicide application, scouting, and cultivation (taken from the ARMS data) bring the total weed control cost to $32.78 per acre for nonadopters. Per-acre weed control costs for adopters ($29.28) are estimated by taking into account the elasticities, ingredient-by-ingredient.

control cost saving (or $3.50 per acre) if herbicide applications, weed scouting, and cultivation expenses, together with herbicide materials, are all included in the calculation of weed control costs (fig. B-4). According to the elasticity-based estimate, weed control cost savings are estimated to range from 1 percent to 34 percent, depending on the production region.

The above $3.50-per-acre savings in weed control costs in the Heartland are reaffirmed by other studies. A recent University of Nebraska study shows that weed control costs for herbicide-tolerant soybeans ($10.45/ac, excluding a seed technology fee of $6/ac.) were about $3/ac. lower than a conventional herbicide program using Pursuit Plus as a herbicide in 1998 (Rawlinson). The costs-of-production

Figure B-4

Impact on weed control cost savings: Herbicide-tolerant soybeans, 1997



Source: USDA's ARMS Survey; Fernandez-Cornejo, Klotz-Ingram, and Jans.

budget for Iowa assumes that in 2001, herbicide program costs for herbicide-tolerant soybeans ($25.2/ac.) were about $4.8/ac. lower than for conventional varieties (Duffy and Vontalge). The smaller savings in weed control costs for herbicide-tolerant soybean adopters from the elasticity-based approach contradicts the much larger savings assumed in the Moschini, Lapan, and Sobolevsky study, where the savings in herbicide expenses ranged from 49 percent to 66 percent, depending on the number (either one or two) of over-the-top Roundup treatments.

Implications for Producer Benefits and Herbicide Use

The above analysis has important implications for the benefits to U.S. soybean farmers and the use of herbicides for controlling weeds in soybean production. This section estimates the benefits to U.S. farmers resulting from the adoption of herbicide-tolerant soybeans and the implications of their adoption for herbicide use in soybean production.

Producer Benefits

According to the elasticity-based estimates, the benefits to U.S. farmers in 1997 are estimated from an on-going ERS study to have been about $60 million, or 20 percent of the total benefits to all stakeholders (including U.S. farmers and consumers, Monsanto, seed companies, and rest-of-the-world producers and consumers) from the adoption of herbicide-tolerant soybeans. This analysis is based on an economic analysis that takes into account the farm-level impacts in terms of the increase in soybean yields and weed control cost savings, price effects resulting from the adoption of the technology, as well as seed premiums and the technology fee (about $7 per acre) for herbicide-tolerant

Table B-3--Differences in weed control costs and herbicide use between adopters and nonadopters of herbicide-tolerant soybeans: Heartland region, 1997

Herbicide Active Ingredient	Rate per crop year	% of area applied	Weight	$/gal	Active ingredient conversion	$/lb	**Herbicide material cost** $/ac nonadoptor	**Herbicide material cost** Elasticity	**Herbicide material cost** $/ac adoptor	**Per-acre herbicide use** lb/ac nonadopter	**Per-acre herbicide use** lb/ac adopter
Acetamides											
Metolachlor	1.9985	4.346	0.0868548	69.5	8.0	8.6875	0.7545512	0	0.7545512	0.0868548	0.0868548
Alachlor	0.8765	2.3327	0.0204461	25.3	4.0	6.325	0.1293217	0	0.1293217	0.0204461	0.0204461
							0.8838728		**0.8838728**	**0.1073009**	**0.1073009**
Glyphosate	0.7104	26.8066	0.1904341	56.7	4.0	14.175	**2.6994032**	0.43	**3.8601465**	**0.1904341**	**0.2723207**
Other Herbicides											
Pendamethalin	1.0738	29.4793	0.3165487	29.4	3.3	8.90909	2.8201614	-0.14	2.4253388	0.3165487	0.2722319
Trifluralin	0.7392	19.591	0.1448167	31.4	4.0	7.85	1.1368109	-0.14	0.9776574	0.1448167	0.1245423
Bentaton	0.6131	9.5323	0.0584425	76.3	4.0	19.075	1.1147913	-0.14	0.9587205	0.0584425	0.0502606
Clomazone	0.5659	4.1989	0.0237616	n.a.		19.9	0.4728553	-0.14	0.4066556	0.0237616	0.020435
2, 4-D	0.3719	9.5672	0.0355804	14.9	4.0	3.725	0.1325371	-0.14	0.1139819	0.0355804	0.0305992
Acifluorfen	0.1403	8.3379	0.0116981	n.a.		28.92	0.3383083	-0.14	0.2909451	0.0116981	0.0100603
Metribuzin	0.2037	10.0828	0.0205387	n.a.		36.9333	0.7585613	-0.14	0.6523627	0.0205387	0.0176633
Imazethapyr	0.0521	42.5628	0.0221752	n.a.		315.9	7.0051516	-0.14	6.0244304	0.0221752	0.0190707
Sethodydim	0.1544	8.0089	0.0123657	101.0	1.5	67.3333	0.8326266	-0.14	0.7160589	0.0123657	0.0106345
Chlorimuron-ethyl	0.0301	13.8682	0.0041743	n.a.		1142.77	4.770297	-0.14	4.1024555	0.0041743	0.0035899
Clethodim	0.0781	4.3617	0.0034065	n.a.		108.99	0.3712731	-0.14	0.3192949	0.0034065	0.0029296
Dimethenamid						14.23	n.a.	-0.14	n.a.	n.a.	n.a.
Fenoxaprop	0.1234	6.8926	0.0085055			165.4	1.4068045	-0.14	1.2098518	0.0085055	0.0073147
Fluazifop-P-butyl	0.048	7.7743	0.0037317			64.83	0.2419238	-0.14	0.2080544	0.0037317	0.0032092
Flumetsulam	0.0554	1.9148	0.0010608				n.a.	-0.14	n.a.	0.0010608	0.0009123
Flumiclorac Pentyl	0.0196	1.2924	0.0002533			215.83	0.054672	-0.14	0.0470179	0.0002533	0.0002178
Fomesafen	0.1694	6.4415	0.0109119			36.34	0.3965385	-0.14	0.3410231	0.0109119	0.0093842
Imazamox							n.a.	-0.14	n.a.	n.a.	n.a.
Imazaquin	0.0786	12.6714	0.0099597	225.0	1.5	150	1.4939581	-0.14	1.2848039	0.0099597	0.0085654
Lactofen	0.0819	4.597	0.0037649			58.71	0.2210398	-0.14	0.1900942	0.0037649	0.0032379
Linuron	0.0527	0.0893	0.000047			24	0.0011295	-0.14	0.0009713	0.000047	0.000041
Quizalofop-ethyl	0.0354	2.5333	0.0008968			143.19	0.1284111	-0.14	0.1104335	0.0008968	0.0007712
Sulfentrazone							n.a.	-0.14	n.a.	n.a.	n.a.
Thifensulfuron	0.0025	9.6446	0.0002411			2084.32	0.5025608	-0.14	0.4322023	0.0002411	0.0002074
Paraquat	0.2725	1.9122	0.0052107			14.47	0.0753995	-0.14	0.0648436	0.0052107	0.0044812
Subtotal							**24.275811**		**20.877198**	**0.6980919**	**0.6003591**
Adjusted subtotal							**24.302199**		**20.899891**	**0.6992696**	**0.6013719**
All herbicides							**27.885475**		**25.643911**	**0.9970046**	**0.9809936**

	Nonadopters	**Adopters**	Difference	% change
Herbicide material costs ($/ac)	27.8855	25.6439	-2.2416	
Herbicide application	3.338	2.875	-0.463	
Scouting	0.291	0.447	0.156	
Cultivation	1.267	0.314	-0.953	
Weed control costs	**32.7815**	**29.2799**	**-3.5016**	**-10.681634**

n.a. = Not applicable.

Source: USDA, NASS (2001 and earlier issues); USDA, ERS.

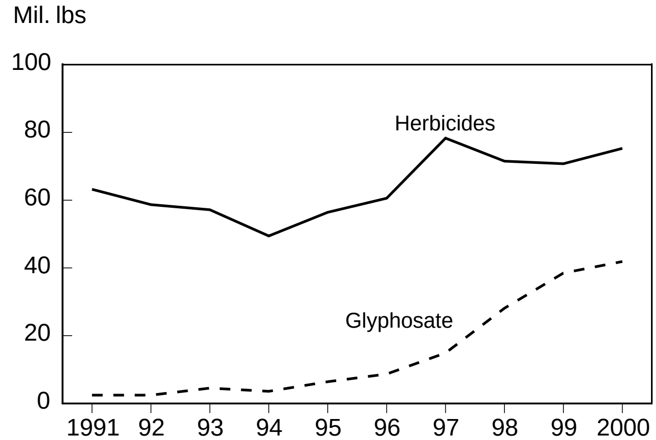
soybean seeds. U.S. farmers who adopted herbicide-tolerant soybeans on 12 million acres of cropland in 1997 gained all these benefits.

The $60-million benefit to U.S. farmers in 1997 based on this study are considerably lower than the $220-million benefit accrued to all U.S. soybean growers in 1998 as estimated by Gianessi and Carpenter. However, these two studies differ in their approaches. The former study compares net benefits between adopters and nonadopters of herbicide-tolerant soybeans in 1997, region-by-region. The latter study attributes the benefits to savings in herbicide costs to all growers in 1998 by taking into account the decline in herbicide prices from 1995 and the seed technology fee ($6 per acre) paid by the adopters.

Similarly, the $60-million benefits are much smaller than the $808-million benefits to U.S. farmers (based on the scenario in which supply elasticity of 0.22 is assumed) in 1997 as estimated by Falck-Zepeda *et al.* The use of the 1997 mean ARMS data in the latter study, which show much larger yield and herbicide cost impacts than the elasticity-based estimates, is a primary factor that contributes to the difference. The benefits obtained from this study also are smaller than the $156-million benefits to U.S. farmers in 1999 estimated by Moschini *et al.*, which were also found to account for about 20 percent of the total benefits to all stakeholders.

Figure B-5

Herbicide and glyphosate applications in U.S. soybean production, 1991-2000



Source: USDA, NASS (2001 and earlier issues).

Herbicide Use

The above analysis of the effect on weed control costs also has important implications for herbicide use and weed control. Biotechnology promises to simplify pest management, reduce the use of chemical inputs, and increase flexibility in field operations. If the adoption of glyphosate-tolerant soybeans leads to savings in weed control costs as well as herbicide use, then the technology will not only benefit producers but also have positive environmental and health benefits.

On a per-acre basis, the use of herbicides in soybean production has been trending down since the introduction of herbicide-tolerant soybeans in 1996, declining from 1.18 pounds in 1997 to 1.06 pounds in 2000. In contrast, glyphosate use has been steadily increasing from 0.23 pound to 0.59 pound during this period. As a result, U.S. farmers used 75.2 million pounds of herbicides on soybeans in 2000, a decline from 78.2 million pounds in 1997 despite a larger planted acreage for the 2000 crop. The use of glyphosate increased from 14.9 million pounds in 1997 to 41.8 million pounds in 2000 (USDA, 2001 and earlier issues; fig. B-5).

The impact of adopting herbicide-tolerant soybeans on herbicide use is not completely clear. The main reason is that while the adoption of glyphosate-tolerant soybeans is estimated to lower the use of "other herbicides" by 14 percent and have no effect on acetamides for adopters, it is estimated to raise the use of glyphosate by 43 percent. Since average application rates vary across herbicide active ingredients, the net effect of substituting one for another may be an increase or a decrease in total pounds used. As a result, the impact on herbicide use is being pulled in opposite directions, depending on whether the decrease in 'other herbicide' use outweighs the increase in glyphosate use.

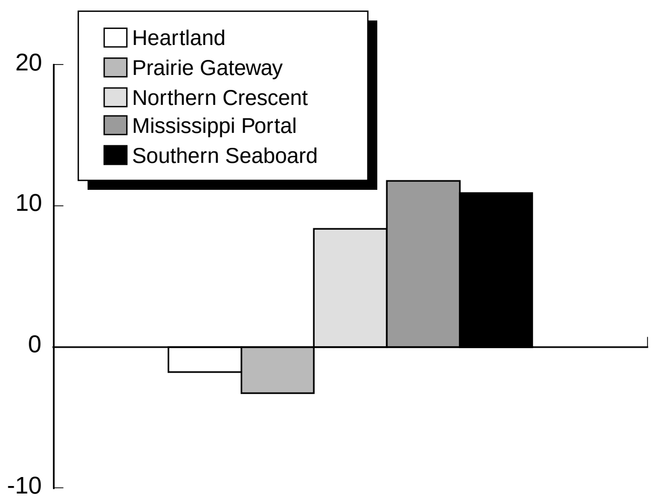
The offsets are most likely in soybean-producing areas that applied herbicides at lower rates and glyphosate at higher rates than the national average—mostly in the South. For example, while Heartland producers may have traded off glyphosate for other herbicides, Southern producers were applying much lower rates of herbicides (e.g., 5.72 lb per acre per crop year in Arkansas in 1997 vs. 9.26 lb in Illinois) but higher rates of glyphosate (e.g., 1.01 lb per acre per crop year in Arkansas vs. 0.66 lb in Illinois). So, when Southern producers started adopting glyphosate-tolerant soybeans and using more glyphosate, there was a much larger proportional increase in total herbicide use, given the differing elasticities estimated for these ingredients. The USDA-NASS chemical usage data supports this relationship (USDA, 2001 and earlier issues).

Results of the analysis show that the impact of adopting herbicide-tolerant soybeans on herbicide use is mixed—a decline for the Heartland and Prairie Gateway, but an increase for all other regions (fig. B-6). Overall, the impact is a slight 3-percent increase in herbicide use (measured in pounds of active ingredients) Nationwide as a result of adopting herbicide-tolerant soybeans. Measuring herbicide use in pounds of active ingredients implicitly assumes that a pound of any two ingredients has equal impacts on human health and/or the environment. However, "other herbicides" being replaced by glyphosate, as a result of the adoption of

Figure B-6

Implications for herbicide use: Herbicide-tolerant soybeans, 1997

% change



Source: Economic Research Service, USDA.

herbicide-tolerant soybeans, are at least three times as toxic and persist in the environment twice as long as glyphosate (Heimlich *et al.*). Thus, adoption of herbicide-tolerant soybeans may lead to positive environmental and health benefits, despite a slight increase in herbicide use.

The decline in herbicide use (in terms of active ingredients applied) for adopters ranges from 1.61 percent in the Heartland region to 3.26 percent in the Prairie Gateway. For example, the use of glyphosate increased from 0.19 pound per acre for nonadopters to 0.27 pound per acre for adopters in the Heartland (table B-3). In contrast, the use of 'other herbicides' decreased from 0.70 pound per acre for nonadopters to 0.60 pound per acre for adopters (table B-3). The end result is a decline in the use of all herbicides from 1.00 pound for nonadopters to 0.98 pound for adopters, or a decline of 1.61 percent, which is lower than the 8-percent decline in herbicide material costs for adopters. The increases in herbicide use for other regions are as follows: 8.35 percent in the Northern Crescent; 11.74 percent in the Mississippi Portal; and 10.89 percent in the Southern Seaboard.

Herbicide-tolerant soybeans offer producers the simplicity and flexibility of weed control, which largely explains why U.S. farmers have adopted this technology so rapidly. Adopters of this technology can rely on one to two postemergence herbicide applications, instead of three or more, to control a broad spectrum of weeds without crop injury. In addition, the adoption of this technology is comparable with the adoption of conservation tillage practices and narrow-row plantings and imposes no restriction on crop rotation (Gianessi and Carpenter). Herbicide-tolerant soybeans also can reduce the foreign material content in soybeans, which is subject to price discounts.

Conclusions

Estimates of the farm-level effects of adopting herbicide-tolerant soybeans differ significantly, depending on the data source. A key challenge to analysts is to isolate the effects of biotech adoption so that estimated farm-level effects can be attributed solely to the technology itself. Estimates of the farm-level effects derived from the elasticity-based approach appear to be more plausible than the mean ARMS data because the farm-level impacts obtained from the former source are attributed exclusively to biotechnology. Nonetheless, the use of one year of data (1997) in this study has its limitations. As more data become available in the future, further analyses including multiple years would provide a more complete assessment of the effects of biotechnology versus management practices and weather.

The farm-level effects of adopting herbicide-tolerant soybeans on crop yields vary across data sources and production regions. Adopters' yields are estimated to be not much different from nonadopters'—only a 3-percent increase for adopters. Adopters' weed control costs in the Heartland are estimated 11 percent lower than for nonadopters (a savings of $3.50/ac.), with the effect ranging from a 1- to 34-percent reduction in other regions. The cost savings have implications for the price premiums necessary to encourage farmers to plant non-biotech soybean varieties instead of the herbicide-tolerant varieties.

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